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13. ABSTRACT *(Maximum 200 words)*

Our long-term research objective is to understand the processes that lead to settlement and fouling by marine species on surfaces immersed in the ocean. This understanding is crucial to the design of coatings that resist or release fouling in environmentally benign ways. To this end, we provided field testing in Pearl Harbor Naval Station for non-toxic antifouling or foul-release coatings under development in cooperating labs. We developed and implemented the first bioassays with tropical species for lab screenings and the new test procedure, the turbulent duct. We have implemented and published on the appropriate statistical amalyses for fouling communities and characterization of the physical properties of coatings. All of this work was geared to take advantage of the real-world setting of our test site in Pearl Harbor that challenges coatings with high rates of year-round settlement by 10 distinct functional groups of tropical species, highlighting the common foulers, Hydroides elegans and Enteromorpha flexuosa and other model species of Balanus and Ulva. These efforts insure that coatings being developed will perform well in the tropical Pacific and other warm water regions.

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Final Report

GRANT #: N00014-95-1-0196

PRINCIPAL INVESTIGATORS: C. M. Smith & M. G. Hadfield

GRANT TITLE: Documentation of the fouling community in Pearl Harbor and its response to novel coatings.

AWARD PERIOD: 1 December 1994 to 31 March 2001

OBJECTIVE: To provide field testing in Pearl Harbor (PHNS) for non-toxic antifouling or foul-release coatings under development in cooperating labs; to develop and implement other tests to screen new coatings or new AF agents effectively; to implement new test procedures such as use of the turbulent duct; and to develop statistical analyses appropriate to fouling communities and physical properties of coatings.

APPROACH: We ran static immersion tests for panels at Ford Island, PHNS for (multiyear) studies. Performance was evaluated via ASTM measures or tests developed for these applications. We also conducted short term field (30 d) and lab (1 d) assays to accelerate testing. Test summaries were reported to collaborators. Multiple collaborative papers published.

ACCOMPLISHMENTS: Our long-term research objective is to understand the processes that lead to settlement and fouling by marine species on surfaces immersed in the ocean. This understanding is crucial to the design coatings that resist or release fouling in environmentally benign ways. To this end, we established and maintain a static immersion field test site at Ford Island's Pier F1½, Pearl Harbor Naval Station (PHNS) (Fig. 1) to test coatings under development in cooperating labs because Pearl Harbor provides a real-world setting that challenges coating with high rates of year-round settlement by a 10 distinct functional groups of tropical species. Further, we continue to accelerate our laboratory testing via addition of new assays with four common PHNS organisms, two invertebrates: *Hydroides elegans* and *Balanus amphitrite* and two green algae: *Ulva fasciata* and *Enteromorpha flexuosa*. The latest innovation is the addition of a calibrated flow cell to study adhesion strengths for common foulers that began in spring 2001. Flow cell studies allow us to bring a new dimension to conventional field measurements as well as provide rapid assessment to collaborators designing new test coatings.

Our most important work to date develops the knowledge of fouling community to a level that we now understand the temporal and spatial patterns that occur. Over the years, we

have evaluated GE DARPA and Carderock NSWC panels as part of a multiyear study of their foul-resistance and fouling adhesion. At our PHNS site, we continue to observe three broad performance classes: 1). Poor performance characterized by steady accumulation of fouling immediately upon immersion. Fouling reached a climax of bivalve/sponges after 150 to 200 d of static immersion. 2). Intermediate performance characterized by low percentages of cover by "early successional species" (such as tubeworms and bryozoans) for an initial 150 to 200 d of immersion. Following that period, fouling is more rapid and the climax bivalve/sponge community is reached after approx. 300 d. 3). Good performance characterized by relatively little fouling by larger hard-foulers for this duration. We have examined the conventional adhesion strengths for tubeworms, barnacles, and bivalves. We have conducted multivariate analyses (principal components analysis) of physical characteristics of coatings as components of multiple regression analysis of fouling and adhesion data as statistical procedures to increase our predictive abilities from the field test data. The addition of calibrated turbulent duct studies will allow us to test relationships between field data sets and precise measures of adhesion strengths for these tropical fouling species. Further this will give us the ability to provide feedback more rapidly to cooperating labs, assuming that the links between performance in the turbulent duct and field tests can be established. These efforts insure that coatings being developed by the Navy will perform in the tropical Pacific and warm waters elsewhere.

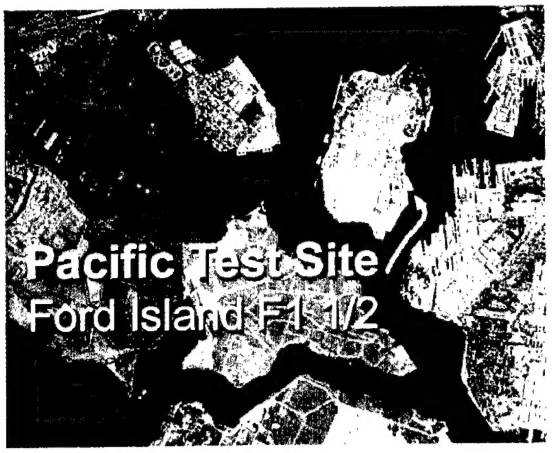

Figure 1. The University of Hawai'i Pacific Test Site is pierside as a static immersion test site, Ford Island (PHNS).

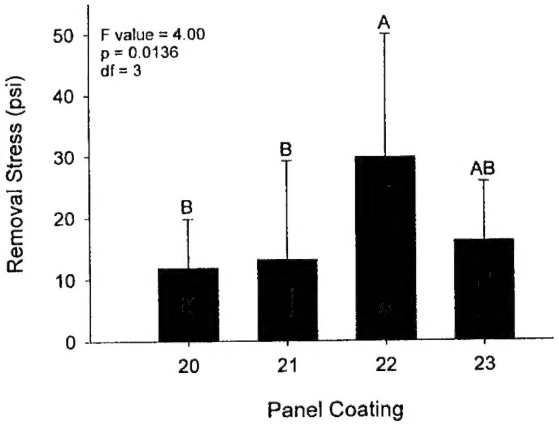

Figure 2. Forces to remove *Hydroides elegans* from select panels immersed at the Pacific Test Site.

CONCLUSIONS: Our multiyear collaboration with GE DARPA and Carderock NSWC in evaluation of the panels led to rapid feedback with these cooperating laboratories (Fig. 2). Data from the GE DARPA analyses has resulted in one publication in the journal *Biofouling* (Truby *et al.* 2000. Evaluation of the performance enhancement of silicone biofouling – release coatings by oil incorporation. *Biofouling* 15:141-50.) Further, adhesion strength data sets are being analyzed for an additional publication. The outcome of testing the rubber panel data set from Carderock NSWC will also be

submitted for publication. GE DARPA provided a selection of prepared surfaces for studies with the turbulent duct; those slides arrived this spring 2001.

SIGNIFICANCE: Our efforts in Pearl Harbor provide real-world testing for candidate coatings challenged by the high rates of year-round settlement of a tropical location and routine impacts of exposure in waters of a Naval Station. We have accelerated our ability to test via implementation of two bioassays based on the species that are principal foulers in Pearl Harbor waters - the polychaete tube-worm, *Hydroides elegans* and the green algae, *Enteromorpha flexuosa* and *Ulva fasciata*, as well as common marine bacteria. Recently, settlement studies with barnacles became a possibility. We applied new approaches to statistically analyze these complex data; many of these approaches will be broadly applicable. Beyond maintaining a static immersion field test site in Pearl Harbor to test coatings under development in cooperating labs, we recently implemented studies with the turbulent duct, a controlled flow cell apparatus as a tool to accelerate laboratory testing. This tool will provide exciting new insight into the forces required to clean surfaces underwater rather than in air as all our previous measures from field testing. In the future, we will work to compare conventional adhesion strengths measured in the field with values determined under precise control in the turbulent duct for common PHNS foulers.

PATENT INFORMATION: None

AWARD INFORMATION: One award was received (MGH with the DP Wilson Lecture, 1998), two MS degrees and one Ph D were supported and conferred, two additional students have been supported during their Ph. D. programs as well as a career promotion (CMS to Professor).

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13) Unabia, C. R. C. and M. G. Hadfield. 1999. The role of bacteria in larval settlement and metamorphosis of the polychaete *Hydroides elegans. Marine Biology.* 133: 55-64.

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16) Truby, K., C Wood, J. Stein, J. Cella, J. Carpenter, C. Kavanagh, G. Swain, D. Weibe, D. Lapota, A. Meyer, E. Holm, D. Wendt, C. Smith and J. Montemareno. 2000. Evaluation of the performance enhancement of silicone biofouling – release coatings by oil incorporation. *Biofouling* 15:141-150.

17) Hadfield, M. G. 2000. Why and how marine invertebrate larvae metamorphose so fast. *Seminars in Cell and Developmental Biology* 11:437-443.

In draft:

Walters, L., C. Smith and M. Hadfield. Recruitment of Sessile Marine Invertebrates on Hawaiian Macrophytes: Do Pre-settlement or Post-settlement Processes Keep Plants Free From Fouling?

Holm, E. R. et al. [continued analysis of DARPA coatings; title to be determined]. To be submitted to *Biofouling*.